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A provenance trial of red spruce in the boreal forest

J. Peter Hall

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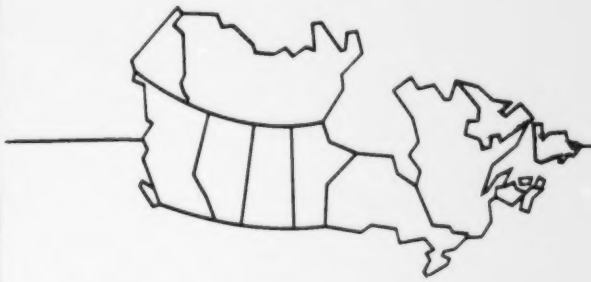

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by J. Peter Hall

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ABSTRACT

Results of a provenance trial of red spruce in the boreal forest at age 25 showed that growth was related to the degree of introgression in certain provenances. Height and diameter were not related to the origin the provenances. Flowering was related to tree height and diameter but not to the origin of the provenances. It was concluded that red spruce has little value as a reforestation species in Newfoundland.

RÉSUMÉ

Les résultats d'un test de provenance d'épinettes rouges âgées de 25 ans dans la forêt boréale ont révélé que la croissance variait selon le degré d'introgression pour certaines provenances. La hauteur et le diamètre ne sont pas reliés à l'origine des provenances. La floraison varie selon la hauteur et le diamètre, mais pas selon la provenance. Il est conclu que l'épinette rouge est une espèce qui ne se prête guère à la restauration forestière à Newfoundland.

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A PROVENANCE TRIAL OF RED SPRUCE IN THE BOREAL FOREST

by

J. PETER HALL

INTRODUCTION

Commercial forest operations in Newfoundland are based on native black spruce (*Picea mariana* (Mill.) B.S.P.), white spruce (*P. glauca* (Moench) Voss) and balsam fir (*Abies balsamea* (L.) Mill.). The small number of species in these commercial boreal forests has prompted the introduction of several exotic species for testing and comparison with local species (Hall 1982). Red spruce (*P. rubens* Sarg.) grows in Ontario and Quebec and in the nearby Maritime Provinces and New England but is not considered to be native to Newfoundland. Early sporadic introductions of red spruce indicated that it was suitable for growing in eastern Newfoundland and this prompted the establishment of this provenance trial in 1964.

Provenance tests are used to screen the natural population of a species to examine variation patterns for use in a tree improvement program. The results of tests indicate the amount of potential improvement in growth, adaptability and resistance to insects and diseases. Gains in productivity can be made by using particular provenances, for example white spruce sources from the Ottawa Valley (Fowler and Coles 1977). Increased resistance to Scleroderris canker (*Gremmeniella abietina* (Lagerberg) Morelet) in jack pine (*Pinus banksiana* Lamb.) can be obtained by using provenances from Quebec (Rudolph and Yeatman 1982).

Red spruce throughout most of its range is sympatric with black spruce and its relationship with that species has been studied in some detail. Introgressive hybridization with black spruce occurs frequently (Morgenstern and Farrar 1964); infrequently (Gordon 1976) or occasionally (Manley 1972). Despite this hybridization both red and black spruce remain as distinct species co-existing in isolated stands and as adjacent pure stands. There are barriers to hybridization which are ecological (Morgenstern and Farrar 1964), genetic (Gordon 1976) and physiological (Manley and Ledig 1979). Despite these barriers, hybrids do occur. Sites intermediate between typical upland red spruce and lowland black spruce have hybrid swarms which become established after clearcutting. The hybrids have been described using a hybrid index system which describes the degree to which the phenotype resembles black or red spruce (Manley 1971). The index has also been used in assessment of the silvicultural potential of the hybrid. Provenances containing hybrids have outgrown those comprised of pure red spruce (Morgenstern et al. 1981, Roche 1969). Hybrids also have a reduced resistance to spruce budworm (Choristoneura fumiferana Clem.) damage (Manley and Fowler 1969) and tend to be more susceptible to drought (Morgenstern 1969) compared to black spruce.

Results from other provenance studies are based on plantations throughout the Acadian and Great Lakes - St. Lawrence Forest Regions (Rowe 1972). This paper presents results of a provenance trial in the Boreal Forest Region; well outside the natural range of red spruce.

METHODS

Planting Site

The plantation is located in east-central Newfoundland (48°42'N, 54°33'W) at an elevation of 105 m. It occupies a shallow southeast-facing slope on a rapidly-drained stony sandy loam soil overlain by up to 10 cm of organic matter. The area has been burned over by wildfire at least three times; in 1886, 1941 and 1961. Cutting occurred prior to the last fire and at the time of plantation establishment there was little ground vegetation or natural regeneration. Because of repeated wildfire the site was of low nutrient status and rapid drainage subjected trees on the site to moisture stress.

Plantation Design

Thirty provenances were tested; twenty-six from Nova Scotia - New Brunswick, two from Maine and two from West Virginia (Appendix I). Plantation design was a randomized complete block with ten replicates of each provenance. Trees were planted in four-tree square plots at a spacing of 1.8 m. The planting stock (aged 2 + 2) was grown at the Acadia Forest Experiment Station Nursery in central New Brunswick, flown to Newfoundland and planted in the spring of 1964. Four rows of trees were planted in a border around the plantation.

Measurements and Analyses

When the trees were 25 years old from seed they were all measured for total height, diameter at breast height, presence of female flowers and hybrid index. The hybrid index was calculated according to

methods developed by Manley (1971) and means were determined for each provenance and for the plantation.

Both height and diameter data were analyzed using 2-way ANOVA of randomized complete blocks with several observations per experimental unit (Steel and Torrie 1960). Correlation coefficients were calculated for height, diameter, hybrid index, level of flowering and origin of the provenances.

Height growth was compared to height at previous measurements and comparisons made between growth of red and black spruce.

RESULTS AND DISCUSSION

Survival

Survival in the plantation was high; one year after planting all dead trees were replaced and four years later only eleven trees had died making overall survival 99.1% (Nickerson 1969). In 1979, 14 years after replacement, survival was 98.7% and this was unchanged by the 25-year remeasurement. Seventeen of the provenances had 100% survival.

Height and Diameter

The provenance means ranked by height and diameter show that both block and treatment effects are statistically significant (Appendix II). The experimental error indicates the presence of interaction; provenances do not behave similarly throughout the plantation. The results of measurements of the border trees showed there to be differences in height from one side of the plantation to the other which may have reflected the reduction in site quality in the lower half of the plantation.

Based on the Analysis of Variance, the means were subjected to the Student-Newman-Keul's multiple range test which is midway between conservative and liberal range tests (Douglas et al. 1981). Three provenances - 14, 17 and 30 - had significantly better growth than all others. The ranking of provenances was similar to that in previous measurements (Khalil 1974, 1981). Correlations between the measurements for both height and diameter were high (Table 1). This suggests that the provenances are stable on the site over time. Those superior in height at age 25 were also superior at younger ages. The four best provenances were in the top four rankings at age 10, 13, 20 and 25. Correlations of diameter over time are statistically significant as well, but lower than for height. This may be caused by the fact that the diameter measurements were not at breast height in the two previous measurements (Table 1). The correlations, therefore, reflect diameter over time and diameter measured at different positions on the stem.

Table 1. Correlation between height and diameter at 25 years, 20, 13 and 10 years.

	Height				Diameter[a]	
	13	20	25		20	25
10	.956**[b]	.831**	.800**	13	.814**[b]	.761**
13		.916**	.894**	20		.973**
20			.990**			

[a]Diameter measured at root collar at age 13 and at 0.6 m on the stem at age 20.

[b]r.05 = .355*, significant at probability level 0.95.
.01 = .456**, significant at probability level 0.99.

Effect of Provenance Origin

Correlation coefficients of height and diameter with origin of the provenances indicate a weak relationship (Table 2). There is no evidence of the clinal variation as shown for black spruce (Morgenstern 1973) but it is quite possible that the overall slow growth of these provenances (213 cm at 25 years) has masked any effects of latitude or elevation. Some correlation of growth with latitude and elevation has been found in other trials of red spruce (Roche 1969, Morgenstern et al. 1981).

Table 2. Correlation of height and diameter with latitude, longitude and elevation of the provenance origins.

	Diameter	Latitude	Longitude	Elevation (m)
Height	.972**[a]	.309	-.082	-.324
Diameter	-	.300	-.061	-.313

[a] $r_{.05} = .355^{*}$, $.01 = .456^{**}$.

Comparisons were also made by grouping the means of various provenances according to the forest section (Rowe 1972) of their origin. Provenances from forest sections A-3 and A-12 (the more productive forest sections in Nova Scotia and New Brunswick) exceeded the plantation mean. Provenances from the Fundy Coast (A-9) and northern Nova Scotia (A-13) were below the plantation mean. The two provenances from Maine were about average and the two provenances from West Virginia were the slowest growing. These differences were small, however, and of little practical

significance. There is no evidence of a group of superior provenances as has been reported to occur for white spruce (Nienstaedt and Teich 1971).

Growth Comparison of Red and Black Spruce

Casual observation of the trees in the plantation indicated a low rate of growth, apparently because of the poor site conditions. No direct comparison of the growth of red spruce with native species was possible as no control species was planted. However, since there was some black spruce natural regeneration on the site these were sampled for height and age and compared with the planted trees. The black spruce were cut as close as possible to the ground and "total" age determined. Trees aged 16, 17, 18 years were 256, 293 and 316 cm tall versus a plantation mean of 178 at age 20. The three best provenances at age 20 averaged 221 cm. Clearly the red spruce was not growing as well as natural black spruce on this site.

On a richer site in western Newfoundland provenances of 20-year old black and red spruce (both from central New Brunswick) averaged 482 and 469 cm respectively.[1] The differences were not statistically significant and the red spruce did not show any indication of superiority or advantage over black spruce on either site. Red spruce grows slowly during the sapling stage and in its mature growth period outgrows black spruce so this early slow growth rate may be temporary.

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[1]Hall 1985, unpublished data.

Effects of Introgression

Results from other provenance tests have shown height to be primarily correlated with hybrid index or the degree of introgression in the provenances (Roche 1969, Morgenstern 1969, Morgenstern et al. 1981). Similar results were obtained in this study (Table 3). There was a

Table 3. Correlation of hybrid index and height of individual trees within seven provenances and between hybrid index and provenance means.[a]

Provenance	Rank	Hybrid index	Correlation coefficient
14	1	.57	-.537**[b]
17	2	.70	-.604**
30	3	.83	-.573**
28	6	.84	-.055
15	9	.89	-.229
13	11	.86	-.062
7	13	.89	+.165
All provenances		.89	-.721

[a]All other provenances had hybrid indices > 0.89.

[b]Significant at P > 0.99.

significant correlation between hybrid index and provenance means. In provenances which had the largest level of introgression, height was also well correlated with hybrid index. Over the whole plantation, 52% of the variation in height was accounted for by the hybrid index. The effect of hybrid index was also found to be statistically significant as young as ten years from seed (r = 0.496**)[2]. The relationship between height and

[2]**Statistically significant at probability level 0.99.

hybrid index is significant when the hybrid index is below .83-.84; when provenances as a whole are nearly pure red spruce the relationship disappears. The trees in the provenances which are apparently introgressed had characteristics of both species; provenances were not composed of some pure black and some pure red spruce. This trend of superiority of introgressed populations has been shown in another population of red and black spruce planted in Newfoundland. A source from central New Brunswick of "black spruce" contained several apparent hybrids with red spruce characteristics. After 20 years the hybrids averaged 506 cm, the black spruce, 469.[3]

Provenances which were introgressed originated in areas where both species occur and where cutting and disturbance is common. Disturbed ar as provide a favourable habitat for hybrid swarms to become established and survive (Manley 1972). Provenance differences measured in this study reflect the integrity of the original collections more than anything else. The significance and value of rapidly growing introgressed populations should not be overlooked however.

Flowering

The trees which produced cones were also tallied when the height measurements were made. The level of flowering was positively correlated with tree size (Table 4). There was a weak negative correlation with the elevation of the seed origin, probably because the two

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[3]Hall 1985, unpublished data.

southern sources were from mountainous areas (1 000 m) compared to the origin of most of the other provenances (< 300 m) and these two sources had very few trees with cones. Introgressed populations also produced more flowers than pure ones. This has implications for the possible use of these hybridized populations in breeding programs.

Table 4. Correlation of percentage flowering with tree size and origin of the provenances.

	Height	Diameter	Latitude	Longitude	Elevation (m)
Percentage of trees flowering	.781**[a]	.700**	.199	-.088	-.295

[a]Significant at P > 0.99.

Silvicultural Implications

The data indicate significant differences among the provenances and that the best provenances are those with hybrid trees. This reflects less upon inter-provenance variation than on the growth rate of hybrids. It would appear that the hybrids have superior growth rate although this is not supported by the literature (Gordon 1976, Manley and Ledig 1979). Hybrids are rare in nature because of ecological, genetic and physiological barriers. They have a better chance of surviving in cultivation, where the competition is less than under natural conditions.

Once established, it appears that hybrids grow well and often better than pure red spruce (Roche 1969, Morgenstern et al. 1981). However, their early growth up to age 25 in Newfoundland was not superior to

black spruce although some individuals grew as well as black spruce. Hybrids are also difficult to produce artificially[4] (Morgenstern 1973). Red spruce is more susceptible to spruce budworm than black spruce but the introgressed populations are more resistant than pure red spruce (Manley and Fowler 1969). Red spruce, including hybrids, are also subject to winter desiccation (Morgenstern 1969, Roche 1969). Trees in the plantation suffered considerable winter damage in 1984 but have since recovered.

CONCLUSIONS

Results of these and previous measurements show that:

(i) Height and diameter rankings of provenances are consistent over the ages 10-25;

(ii) Introgression is common in several of the provenances;

(iii) Growth of the trees was related to hybrid index, not the origin of the provenances;

(iv) Flowering was related to height and hybrid index and not to the origin of the provenances;

(v) The results have little silvicultural application in Newfoundland because there is no apparent advantage in using red spruce as a reforestation species over black spruce.

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[4]Hall, unpublished data.

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APPENDIX I

ORIGIN OF PROVENANCES

No.	Origin	Latitude	Longitude	Elevation (m)	Forest section[1]
1.	Napadogan, York Co. New Brunswick	46°24'	66°59'	260-275	A-2
2.	Great Salmon River, Saint John Co., New Brunswick	45°25'	65°25'	105-275	A-9
3.	Timber Lake, Lunenburg Co., Nova Scotia	44°41'	64°09'	75-120	A-11
4.	Sisters Brook, York Co., New Brunswick	46°37'	66°40'	230	A-2
5.	Scott's Bay, King's Co., Nova Scotia	45°18'	64°24'	0-150	A-9
6.	Corberrie, Digby Co. Nova Scotia	44°10'	65°55'	45-60	A-11
7.	Waverley, Halifax Co., Nova Scotia	44°47'	63°35'	30-75	A-11
8.	Headwaters, E. Sheet Harbour R., Nova Scotia	45°13'	62°44'	185	A-11
9.	Hart's Lake, Colchester Co., Nova Scotia	45°34'	63°31'	275-305	A-3
10.	Economy River, Colchester Co., Nova Scotia	45°29'	63°56'	185	A-13
11.	Canaan Mountain, W. Virginia, U.S.A.	39°05'	79°30'	670-915	-
12.	Monongahela National Forest, W. Virginia, U.S.A.	38°40'	79°37'	1 145-1 250	-

Appendix I (Cont'd.)

No.	Origin	Latitude	Longitude	Elevation (m)	Forest section[1]
13.	New River Watershed, Charlotte Co., New Brunswick	45°13'	66°33'	60-90	A-9
14.	Upper Blackville, New Brunswick	46°39'	65°51'	60	A-3
15.	Rocky Brook, York Co., New Brunswick	46°38'	66°37'	245-305	A-2
16.	Acadia Forest. Exp. Stn., New Brunswick	46°01'	66°15'	60	A-3
17.	Boyne Road, Sunbury Co., New Brunswick	45°33'	66°31'	45	A-3
18.	Lakelands, Cumberland Co., Nova Scotia	45°28'	64°20'	30	A-12
19.	Chezzetcook, Halifax Co., Nova Scotia	44°45'	63°14'	30	A-11
20.	South Paradise, Annapolis Co., Nova Scotia	44°51'	65°12'	105	A-12
21.	Blanchard, Pictou Co., Nova Scotia	45°28'	62°27'	215	A-13
22.	Snare Lake, Colchester Co., Nova Scotia	45°35'	63°29'	335	A-3
23.	West of Five Mile Lake, Hant's Co., Nova Scotia	44°51'	64°00'	150	A-11
24.	Crooked Creek, Albert Co., New Brunswick	45°49'	64°48'	275	A-9
25.	West of Great Salmon River, Saint John Co., New Brunswick	45°25'	65°26'	185	A-9

Appendix I (Concl'd.)

No.	Origin	Latitude	Longitude	Elevation (m)	Forest section[1]
26.	Penobscot Forest Exp. Stn., Maine, U.S.A.	44°52'	68°38'	45	-
27.	Evans Brook, Annapolis Co., Nova Scotia	44°42'	65°21'	185	A-12
28.	Little Black River, Maine, U.S.A.	47°13'	69°14'	215-365	-
29.	Nictaux West, Annapolis Co., Nova Scotia	44°55'	65°06'	15-30	A-12
30.	Mush-a-mush and Spondo Lakes, Lunenburg Co., Nova Scotia	44°32'	64°29'	90-120	A-11

[1] Rowe 1972.

APPENDIX II

RANKING OF PROVENANCES BY HEIGHT AND DIAMETER AND ANALYSIS OF VARIANCE AT AGE 25

Prov. No.	Height Avg. ht. (cm)	SNK-test	Rank	Prov. No.	Diameter Avg. diam. (cm)	SNK-test
14	297		1	14	3.1	
17	264		2	17	3.0	
30	257		3	30	2.9	
16	239		4	16	2.6	
20	239		5	28	2.6	
28	238		6	29	2.6	
18	237		7	3	2.5	
29	236		8	15, 20	2.4	
15	236		9	20, 15	2.4	
3	229		10	18	2.4	
13	220		11	13	2.3	
27	218		12	1	2.1	
1	213		13	4	2.1	
5	212		14	2	2.1	
4	208		15	5	2.0	
19	207		16	27	2.0	
9	207		17	19	2.0	
6	205		18	12	2.0	
12	205		19	21	1.9	
2	199		20	6	1.8	
21	198		21	26	1.8	
26	195		22	9	1.8	
7	194		23	23	1.7	
23	188		24	7	1.7	
24	187		25	24	1.6	
22	177		26	22	1.5	
25	173		27	8	1.3	
8	170		28	25	1.3	
10	168		29	11	1.2	
11	165		30	10	1.2	
Plantation mean	213				2.1	

ANOVA		Height			Diameter		
Source	dF	SS	MS	F	SS	MS	F
Blocks	9	47.346	5.261	9.21***	143.48	15.94	8.17***
Provenances	29	110.599	3.814	6.73***	357.04	12.31	6.31***
Blocks x prov.	261	225.017	.862	1.51***	790.32	3.03	1.55***
Error	884	503.652	.571		1721.56	1.95	
Total	1183	886.614			3012.41		